NOCTIS LANDING, MARS: REGIONS OF INTEREST WITH DIVERSITY OF HYDRATED MINERALS.

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Summary: Noctis Landing, a proposed human Landing Site and Exploration Zone in West Valles Marineris, Mars, presents hydrated minerals attesting to a complex aqueous history and opportunities for future human exploration.

Introduction: In October 2015, NASA convened the *First Landing Site (LS)/Exploration Zone (EZ) Workshop for Human Missions to the Surface of Mars* [1]. Among 47 proposed LS/EZs was *Noctis Landing* (6°29.5'S, 92°27.2'W), a regional depression between Noctis Labyrinthus and Valles Marineris **(Fig. 1).**

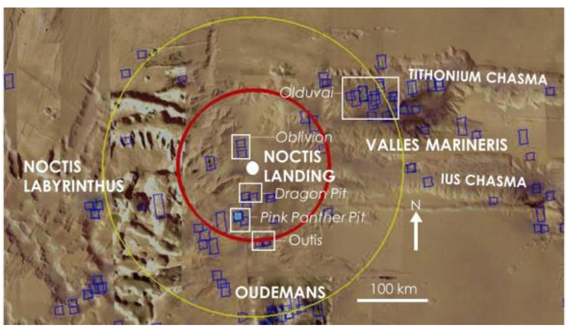

Figure 1. Noctis Landing Map. Red: Primary EZ (PEZ). Red to Yellow: Secondary EZ (SEZ). Boxes locate MRO CRISM coverage examined in this study (Base map: NASA/Google).

In this study, we assess the distribution of hydrated minerals, in particular opal (a hydrated silicate), phyllosilicates (e.g., illite), and jarosite (a hydroxylated sulfate) from Mars Reconnaissance Orbiter (MRO) Compact Reconnaissance Imaging Spectrometer for Mars (CRISM) infrared spectral data, with the goal of identifying regions of interest (ROIs) for science and potential resources at the Noctis Landing (NL) LS/EZ. We follow standard CRISM processing techniques, including atmospheric and photometric corrections, and check for spurious signatures following [3]. Jarosite and opal were previously reported in [4,5,6]. We begin analyzing here their formation mechanisms in NL, which will help constrain the past history of the LS.

Results:

Northern Sector of Noctis Landing Primary EZ. Closest to the NL LS, two CRISM images were acquired ~22 and ~35 km NNW of the NL LS, over areas presenting Light Toned Deposits (LTDs). We refer to this potential ROI as *Oblivion* **(Fig. 2)**. Some outcrops bear clear signatures of opal **(Fig. 2B),** while others show a doublet absorption at 2.2-2.3 µm which is well matched in position, width and depth by a mixture of illite (an Al-phyllosilicate) and jarosite **(Fig. 2C)**.

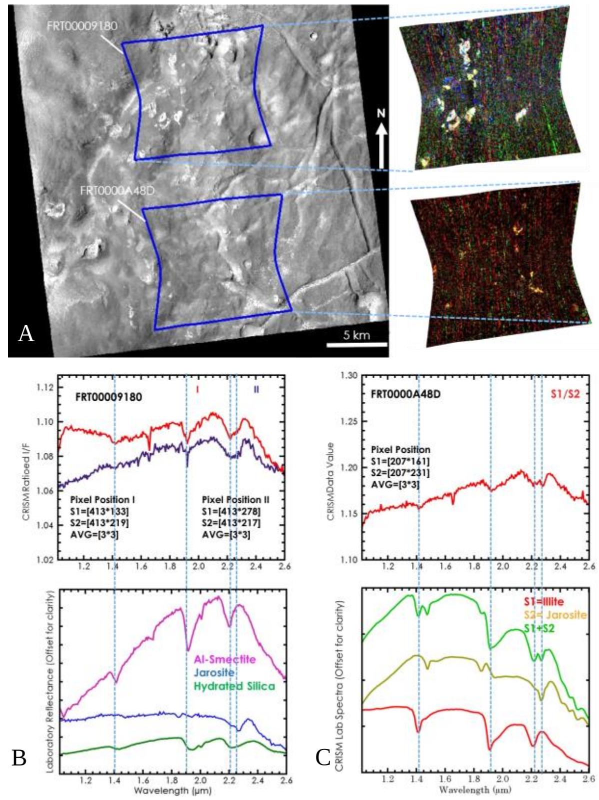

Figure 2. Hydrated Minerals at *Oblivion*. A-Left: MRO CRISM stamps on CTX background image with LTDs. **A-Right:** Browse Product HYS showing mixed spectra from opal, Al-phyllosilicates, and/or jarosite (white and yellow). **B.** Spectral ratio for FRT00009180 indicating hydrated silica (opal) in the LTDs. **C.** Spectral ratio for FRT0000A48D likely indicating a jarosite / Al-phyllosilicate (best match is illite) mixture, producing doublet at 2.2-2.3 µm.

There are many more LTD exposures with likely hydrated minerals north of the NL LS beyond *Oblivion*, including some closer to the NL LS.

Southwestern Sector of Noctis Landing Primary EZ. We previously described pits with LTDs ~40 km SW (*Dragon Pit*) and ~70 km SW (*Pink Panther Pit*) from the NL LS [4]. *Dragon Pit* has a ~300m tall central mound with mafics at its base, a section with polyhydrated sulfates above, and jarosite at its peak. *Pink Panther Pit* has dunes on its floor and LTDs with jarosite along its rim and downhill streaks [4].

Southern Sector of Noctis Landing Secondary EZ. At 100 km S of the NL LS, on LTD hills in candidate ROI *Outis*, we report hydrated Fe-Mg phyllosilicates, with vermiculite as best match, and opal **(Fig. 3)**.

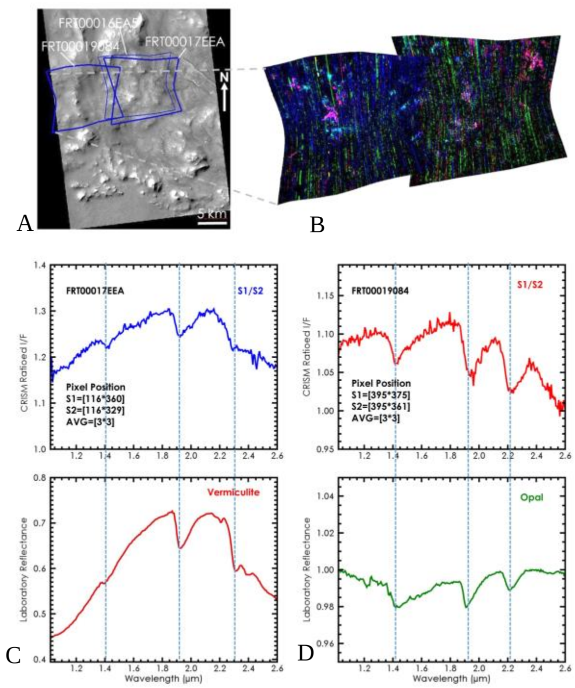

Figure 3. Vermiculite in *Outis*. A. MRO CRISM stamps on CTX background image with LTDs on hills. **B:** Browse Product PHY shows Fe-Mg phyllosilicates in magenta and other hydrated minerals like opal in blue. **C.** Spectral ratio matches vermiculite, an Fe-Mg phyllosilicate, and **D.** opal

Northeast Sector of NL Secondary EZ. At ~200 km NE of the NL LS, there are multiple exposures of LTDs on the walls and floor of Tithonium Chasma in candidate ROI *Olduvai* **(Fig 4)**. All CRISM infrared images here bear signatures of hydrated sulfates **(Fig. 4B)** and a few occurrences of hydrated silica **(Fig. 4C)**.

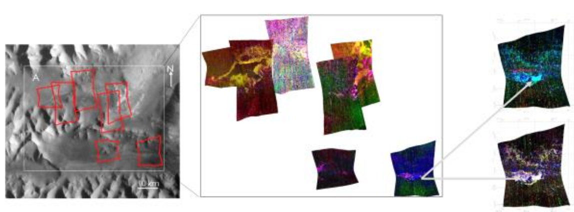

Figure 4. Hydrated Sulfates in *Olduvai*, Tithonium Chasma. A. MRO CRISM stamps overlain on Mars Express HRSC image showing *Olduvai*. **B:** Browse Product HYD showing hydrated sulfates (magenta), green (monohydrated sulfates), yellow (mixtures of monohydrated and polyhydrated sulfates), and blue (for other hydrated minerals such as silicates). **C.** Browse product PHY (top) and HYS (bottom) indicating the presence of opal and/or Al-phyllosilicate

Discussion:

Insights from opal. Opal is observed in LTDs at *Oblivion*, *Outis*, and possibly *Olduvai*, in association with phyllosilicates and sulfates. Opaline silicates are usually tied to hydrothermal systems and have the highest potential of preserving biosignatures, confirming *Oblivion* and *Outis* as ROIs at NL.

Insights from phyllosilicates. Illite, an Al-phyllosilicate, is observed as best spectral match candidate in *Oblivion*, where it is spectrally mixed with jarosite/opal. Illite and jarosite are both indicators of aqueous conditions. However, illite implies high pH and abundant water, whereas jarosite implies low pH and limited water, indicating a change in aqueous conditions at *Oblivion* through time. At *Outis*, Fe-Mg phyllosilicates (smectites) are best matched by vermiculite, reported here likely for the first time.

Insights from sulfates. Jarosite, a hydroxylated sulfate [(K, Na) Fe_3^{+3} $(SO_4)_2(OH)_6$], is observed in LTD patches at *Dragon Pit*, *Pink Panther Pit*, and *Oblivion*, adding to other sulfates reported at NL, including monohydrated sulfates (e.g., kieserite ($MgSO_4.H_2O$)) and polyhydrated sulfates [4]. Jarosite is uncommon on Earth (associated with acid-mine drainage) but common on Mars. Its stability is explained by the interaction of highly acidic water with basalt, while a low water to rock ratio is maintained in an oxidizing environment. Possible depositional environments include evaporative basins, groundwater upwelling in topographic lows, subglacial meltwater [7], ice-weathering [8] in open basin, and fog weathering (could take ~10^8 yrs for deposition). The possibility of jarosite deposition as paleo-ice deposits in subglacial meltwater or englacial weathering of dust challenges *warm & wet* climatic models of Mars [7,9,10].

Conclusion: The presence of multiple kilometer long exposures of hydrated minerals at Noctis Landing, such as opaline silica, Al-phyllosilicates (likely illite), Fe-Mg phyllosilicates (vermiculite), monohydrated and polyhydrated sulfates, and hydroxylated sulfate (jarosite) adds to the science (astrobiology, geology) and exploration (ISRU) ROIs accessible from NL LS.

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